CONTENTS

A. GENERAL DESCRIPTION

The following manual describes the STELAR Variable Temperature Controller VTC91. It is intended as a general guidance for the operator. It corresponds closely to the actual unit in terms of hardware configuration, software structure, and performance. Any deviations regard optional accessories which are described as installed but which need not be ordered and therefore may be missing in the delivered equipment.

STELAR claims the right to implement without warning additional options, modifications and improvements resulting from the ongoing development of the product. This manual therefore corresponds to the minimum performance of a fully equipped unit.

The product conforms to the security norms of most countries (in particular the EEC and USA regulations). Mains voltage is only applied to the mains switch with its incorporated fuse and to the primary of the mains transformer. It is nowhere accessible to a naked human hand. Voltages at any other point do not exceed 30 V DC. Shorting and interconnecting any input or output lines in any way can not cause harm to the operator. It actually should not damage the instrument either, even though we will not guarantee that in written.

The product comes normally with a 12 month warranty. Most service, if needed, can be done by simple exchange of its plug-in printed circuit boards. More complicated problems may require shipping the unit to factory. In such a case, please take great care of its packaging. STELAR can not take over the responsibility for any damage caused by transport.

DISCLAIMER

Since our VTC controllers are general-purpose devices and STELAR cannot foresee all the uses to which they will be put, we disclaim responsibility for any kind of damage to persons or property which might occur concurrently with their use.

A.1 INTRODUCTION

VTC91 is a self-contained, digital temperature controller (optionally usable also to control other experimental conditions or process variables).

It has *two power outputs*: one for the temperature controlling device (usually a wire resistor inserted into a gas flow), and one for an auxiliary load such as a liquid nitrogen evaporator. Both outputs are digitally controlled, high-precision amperostats controlling the output currents. They are physically identical, any apparent differences are due only to the way they are employed by the instrument's software.
Apart from the *power output modules*, the *control hardware and firmware* and the *sensors*, the unit contains also a *gas flow regulator*, as well as a number of *safety interlocks.*

At least one sensor channel is always implemented (we will refer to it as the *control channel)*. An optional sensor channel, normally used as an independent monitor, is also foreseen (we will call it the *monitor channel*). The sensors are normally *thermocouples* (types J,K,T), but *platinum wire sensors* (PT100) are also compatible with the input circuitry, provided the choice is made upon order. In the case of a thermocouple sensor, the control channel can be set for two different operating modes, depending upon the desired reference joint: *compensated reference joint* using the Analog Devices transducer AD595 or, optionally, a *true reference joint* using a reference thermocouple kept at a well defined reference temperature (ice+water bath, liquid nitrogen bath, etc...). In both cases, the

implemented transducers are thermostated in order to eliminate any residual effect of the room temperature variations.

The high resolution (sensitivity) and reproducibility of the temperature measurements is also due to the following factors:

- The *resolution of an ultralinear, true 16-bit analog-to-digital converter*, permitting to detect temperature variations of the order of 0.01° while still covering the whole range of temperatures physically compatible with any sensor. Thus no range switches and similar devices are necessary.
- *Each actual reading is the mean value of a programmable number of single measurements*. This permits to increase considerably the already high basic resolution and suppress the sensor and transducer noise.
- *During each reading, the instrument executes a self-calibration cycle* consisting of measuring the sensor voltage as well as the apparent ground and an reference voltage diode. This implies signal multiplexing and digital evaluation, but it eliminates almost all electronic circuitry imperfections such as offsets and drifts of operational amplifiers, room-temperature dependence of resistor and capacitor values, power supply variations, etc. The result is a long-term reproducibility better then 0.1°.

Apart from the resolution (sensitivity) and reproducibility of temperature measurements, one is often interested also in their *absolute precision*. The three parameters are in fact almost independent of each other. A measuring device can, for example, excel in any two of them while performing badly with respect to the other one. The basic absolute precision of our controllers is not particularly high. We rely on the performance of the commercially available transducers (such as the AD595) and thermocouples. Since both belong to the +-0.1° category, the inherent absolute precision is about +-2°. However, the unusually high sensitivity and reproducibility of the instrument makes it possible to calibrate it in terms of temperature and reach considerably better absolute precision performance. Resident software makes it possible to execute a *guided one-point or two-point calibration of any of the implemented sensors*. Once calibrated, the absolute precision of the instrument becomes comparable to its inherent reproducibility (a warning: it is difficult to find guaranteed temperature references; the simple freezing and boiling water baths become unsuitable for precision levels of 0.1° or below). The calibration of a sensor consists of a digital correction of the corresponding transducer offset and gain. It has nothing to do with the linearization of the sensor which will be discussed in the next paragraph.

Sensor linearization is made digitally using polynomial fits to the standard thermocouple tables as listed by the *International Electrochemical Commission (IEC)*, publications n. 584-1 and 584-2 (for thermocouples) and 751 (for platinum wire thermometers). These data represent the most recent basis for international standardization of temperature measurements and serve as a source for almost all national standards such as DIN, British Standard, UNI-CTI 7938 and 7937, etc. The tabulated data were interpolated by polynomials and/or rational of a sufficiently high degree to achieve *maximum deviation smaller than 0.05°*. Since all calculations are carried-out internally with full 10 decimal digits precision, *errors due to truncation and rounding are negligible*. Users should keep in mind that the internationally standardized data are approximations to the idealized physical temperature appearing in thermodynamical formulae. The goal of the national and international standardization organizations is to keep the approximation as good as possible. Periodically, corrections are made and the decreasing magnitude of such corrections provides a measure of confidence for the standardized values. For the temperature ranges of different TC types, the estimated confidence level is currently about 0.05°.

During temperature control, a *feedback loop* is established which includes the thermostated object *(thermal load)*, the *sensor*, the *controller* (active element), and the *power source*. For

any controller, there are two distinct operating phases: the transition to a new set-point (locking phase) and the stationary behavior at set-point (the locked-loop phase).

The two phases give rise to two distinct sets of performance criteria:

- For most practical purposes, the locking phase is characterized by *settling time* and *overshoot*.
- The most important parameters of the locked-loop phase parameters are the mean-square deviation from the set-point *(stability)*, the oscillatory components *(spectrum)*, the transient response to small variations in the thermal load *(rigidity)*, etc. In particular, the mean-square deviation from the set-point is always higher than the precision of the unit when used as a simple measuring device. We call the difference between the two quantities *loop noise*. Ideally, the loop noise should be zero, but that would require a noiseless sensor and an absolutely perfect control algorithm. Unfortunately, it is impossible to rigid controller specifications unless the thermal load is also defined, since this part of the loop has a crucial effect on the controller performance.

Changing a thermal load requires a change in the control algorithm parameters; there is no (and never will be !) fixed- configuration, universal controller. On devices controlled by analog circuitry, the re-configuration consists in changing the settings of switches and variable resistors. On digital devices such as ours, it consists in editing the values of a number of digital parameters (a much more versatile approach). In principle, it is possible to envisage a device which could "learn" from experience and refine the control parameters; our unit does not behave in that way, but it could implement such algorithms (should they become available in the future) without any hardware modification.

The *control algorithm* uses a set of control parameters stored in a non-volatile memory; these permit *performance optimization for practically any type of thermal load*. Negligible overshoot, control stability better than 0.1°, and locking within 3 minutes are characteristic for most situations. The device can *memorize a number of distinct parameter tables* in order to make it easy to switch between different loads and/or operating conditions (e.g., high/low temperature region).
Since the control is carried out in terms of power rather than current or voltage, *it is efficient even when the difference between the control gas temperature and the set-point is quite small* (e.g. 2°). Other salient feature is the high-resolution control of the output power channels (2048 steps). These features are normally not found in commercial VT controllers.

A.2 FRONT PANEL DESCRIPTION (SEE DRAWING)

The front panel contains the following devices:

- 16-character LCD alphanumeric display.
- 16-key keyboard with the following keys:
  Digits : 0, 1, 2, 3, 4, 5, 6, 7, 8, 9
  Special keys : RST CAL/PRG FRM/. +/- ENT/PRT
  Paper advance : ADV (effective only with the optional printer)
- LED (Light Emitting Diodes) indicators:
  Power supply : Indicates that the instrument is ON
  Heater : Indicates that the heater output is enabled
  Evaporator : Indicates that the evaporator output is enabled
  Interlock : Indicates that an interlock has been tripped.
  Interlocks are internal safety protection whose task it is to stop erogating power to heater and/or evaporator if anything goes wrong.
- Gas flowmeter/manual regulator with an interlock switch.
- 15-column thermal printer (optional)

A.3 REAR PANEL DESCRIPTION (SEE DRAWING)

The rear panels (left and right) contain the following devices:

RIGHT PANEL
- Carrier gas inlet and outlet for the gas flowmeter.
- Mains connector with an incorporated slow-blow fuse holder.
- Cooling fan

LEFT PANEL
- Connector TC1 for the compensated control thermocouple
- Connector TC2 for the compensated monitor thermocouple
- Connectors TC3 and REF for the differential arrangement with a control thermocouple (TC3) and a true reference junction thermocouple (REF).
- RESET : CPU reset push-button
- HEATER : 7-pin connector for the heater assembly including also a safety TC input.
- EVAPORATOR : 7-pin connector for the evaporator assembly including also a safety TC input.
- ALARM : An optional connector for external alarm device
- RS232 : An optional communication connector

B. SPECIFICATIONS

* **DIMENSIONS** : Table-top version
  : W54 x H18 x L35 cm
  Rack mounted version : 19" x 3units x 35cm
* **WEIGHT** : 8 kg
* **MAINS** : 220Vac/50Hz/3A (optional 115Vac/60Hz/6A)
* **GAS FLOW REGULATION** : manual, 0-300 nl/h or 0-1.5 nm^3/h
* **CONTROL OUTPUT POWER** : max 120W (30V, 0-4A)
* **CONTROL OUTPUT RESOLUTION** : 11 bit (2048 steps)
* **EVAPORATOR OUTPUT POWER** : max 120W (30V, 0-4A)
* **EVAPORATOR OUTPUT RESOLUTION** :11 bit (2048 steps)
* **ADC** : ultralinear 16 bit/5msec
* **CPU** : Z80/2.5MHz/16K ROM/8K RAM/8K EEPROM
* **AUTOMATIC SELF-CALIBRATION** of the ADC converter
* **SENSOR CHANNELS**:
  * Control channel with two operating modes:
    - compensated reference junction and
    - true reference TC junction (optional)
  * Monitor channel with compensated TC junction (optional)
* **SENSORS** : Thermocouples (types J,K,T)
  - Temperature measurement specifications:
  Range : -270 to +400 °C for type T (Cu-Const)
  : -200 to +300 °C for J,K (to be extended)

  Reproducibility : <0.1°C
  Resolution : <.01°C
  - Temperature control specifications (typical values; exact specifications depend upon the controlled system)
  Range : from -160 to +180 °C
  Stability : <0.1 °

* **CONTROL ALGORITHM**: generalized PID with input filter/predictor, integral action band, second-derivative damping, integral look-ahead damping, output step limit, etc.
* **SPECIAL FIRMWARE FEATURES**:
  - Separate calibration of each sensor channel & mode
  - Independent Set-Point calibration
  - Amperostat operating modes, etc (see the manual).
* **SAFETY INTERLOCKS**:
  - BROKEN TC : Interrupted thermocouple circuit
  - TEMP.TOO HIGH : Main sensor temp. exceeds a soft limit or a safety TC temp. exceeds a hard limit
  - MISSING FLOW : Missing flow of the carrier gas
  - MISSING N2 : No liquid nitrogen in the evaporator
  - A hard-wired interlock will trip should the CPU fail.
* **Self testing capabilities**: automatic ADC calibration tests and EEPROM data tests (programs as well as control parameters).

OPTIONAL ACCESSORIES:

* 15 column thermal printer * serial RS232 interface
* parallel interface * Xt or XY plotter interface
* Digital plotter interface * Acoustic/visual alarms
* Special application firmware * Programming kit
* Pt100 sensors and sensors for pressure, pH, humidity, etc.

C.1 CONNECTING THE THERMOCOUPLES

a) Insert the control thermocouple into whatever device is to be controlled (NMR probe, EPR cavity, etc).

b) *Plug the control TIC into the rear panel connector TC 1* if you want to use the internal compensation of reference junction.
Plug the control TC into the rear panel connector TC 3 if you want to use an external reference thermocouple. In this case, plug the reference TC into the adjacent *TC REF* connector.

c) If you want to use it, *plug the optional monitor thermocouple into the rear panel connector TC 2.*

A disconnected (or misconnected) control thermocouple trips an interlock and causes the error message *"BROKEN SENSOR"* to be displayed. The program also tests whether the monitor channel is available and uses it only if installed. In those situation where the monitor TC is required (e.g., in the monitor sensor calibration routine), its absence will be indicated by the message *"MISSING SENSOR"*.

C.2 OPERATING ABOVE ROOM TEMPERATURE

a) Connect the control thermocouple as described above.
b) Insert the heater into its place (usually a probe or cavity dewar) and connect it to *HEATER* socket on the rear panel.
c) Connect the flowmeter inlet, *AIR IN*, located on the right rear panel, to a supply of dry, compressed air or nitrogen (1-2 Atm). If a compressor is used as a supply, insert suitable filters between the compressor and the instrument to prevent dust accumulation and water condensation.
d) Connect the flowmeter outlet , *AIR OUT* on the right rear panel, to the carrier gas inlet at the thermostated device(usually a probe or cavity dewar with a spherical joint).
e) Set a correct flow level on the flowmeter/regulator (carrier gas flow is a important control parameter).

Note: Use flexible tubing of about 4-5 mm internal diameter and about 6 mm of external diameter for the air inlet and outlet connections.

The unit is now ready and you can run the control program. See the Standard Operations section for further details. During temperature control, several safety interlocks may be tripped if, for any reason, a pathological condition occurs. Whenever an interlock is tripped, the *interlock light* on the front panel switches ON and output power channels are automatically disabled.

If no gas flow is detected by the flowmeter while the control program is operative, an interlock is tripped and the error message *"MISSING AIR"* is displayed. This interlock is ignored and no message occurs if you are using a liquid nitrogen evaporator.

If the *safety thermocouple* in the heater assembly detects a temperature higher then the threshold set by the trimmer *P1* of the *VT INPUT* board, an interlock occurs and the error message *"SAFETY TC HOT"* is displayed. The threshold is factory-set to +250 C. Refer to the Hardware Calibration section for more details on setting this safety interlock.

C.3 OPERATING BELOW/ABOVE ROOM TEMPERATURE WITHOUT EVAPORATOR

It is possible to increase the range of available temperatures by *precooling the carrier gas*. This is usually done by using a spiral or serpentine *heat exchanger* made of a suitable metal tubing (copper, stainless steel, brass) and *immersed in a suitable cold bath*. The baths used more often are liquid nitrogen, dry ice - acetone mixture, and electrically refrigerated ethylenglycol.

The connections are identical to the preceding case except that the heat exchanger is inserted between the flowmeter outlet at the instrument and the carrier gas inlet at the thermostated device (probe or cavity dewar). It is also recommendable to reduce refrigeration loss in the section between the heat exchanger and the thermostated device. According to the specific temperature range, this is done either by a spongy plastic cobimentation or by a transfer dewar.

WARNING

BE CAREFUL NOT TO INVERT THE ORDER AND COOL THE GAS BEFORE PASSING THROUGH THE FLOWMETER.

Once connected, the operation as well as interlocks are identical to the preceding case. The only difference is an extended lower limit of controllable temperatures. However, at set-

points above room temperature the instrument will have to apply more power to the heater. It may happen that the upper limit of the accessible temperature interval will become too low for your application due to insufficient maximum heater power. In this case you must either try to increase the maximum output power (see the Hardware Calibration section) or to renounce covering the whole temperature range with a single set-up. Usually there is enough output power to cover about 200°C interval.

C.4 USING THE LIQUID NITROGEN EVAPORATOR

The liquid nitrogen evaporator is probably the best solution for prolonged operations at low and very low temperatures, even though temperatures close to or above room temperature are normally also accessible in this set-up.
The connections are made as follows:
a. Insert the control thermocouple as described above.
b. Connect the evaporator cable to the "EVAPORATOR" socket on the left rear panel.
c. Fill the evaporator dewar with liquid nitrogen.
d. Immerse the evaporator rod slowly and wait a while until it reaches thermal equilibrium.
e. Secure the evaporator rod with the clamping ring.
f. Connect the dewar transfer line between the evaporator and the thermostated device.

The unit is now ready and you can run the control program. See the Standard Operations section for further details. Like in the previous cases, several safety interlocks may be tripped during the temperature control.

An interlock occurs if the safety thermocouple in the evaporator assembly detects a temperature higher then the threshold set by the trimmer *P2* of the *VT INPUT* board. In this case, the error message *"MISSING* N_2*"* is displayed. The threshold is factory set to 0 °C. Refer to the Hardware Calibration section for the setting this threshold.

D. STANDARD OPERATION

The unit is quite easy to use due to the presence of the *alphanumeric display* which permits a *menu-based interaction* with the operator. There are a few points you should remember:

- Whenever a blinking *cursor* (a large black box character) appears on the display, the unit is explicitly waiting for a keyboard input and any other activity is stopped. *Should any of the two output power channels be active, it will be turned off if no key has been pressed for more than about 35 seconds.*

- If the cursor is not present, the unit is operating but still keeps an eye on the keyboard *(background keyboard monitoring)*. By pressing one of the keys you can interrupt the current task. To do so, you should know the effect of each key as described in this manual; it may differ according to the current operating phase. Keep in mind that the system always reacts to a key only after it has been released (if you keep a key pressed, the software cycles in a loop and any other activity is suspended). Moreover, in the case of background monitoring, the reaction to pressing a key may occur only after a noticeable delay (up to 2 seconds) since all internal cycles must be terminated before the current task interruption.

- In some cases, the unit will present queries to the operator. A *query* is a string followed by a question mark and a blinking cursors. You can answer it either *"YES" by pressing the "ENT"* key or *"NO" by pressing the "RST"* key.

- Whenever a prompter string without any question mark appears, the unit requires a *numeric input*. Numerical values may be entered in any format; just press the appropriate keys. After pressing the first key, the display will clear and indicate +0. Press the key +/- if you want to change the sign. Then press the digit keys and the eventual decimal point followed by decimal digits. After at least one significant digit has been input, pressing the +/- key will start input of an optional exponent. Upon a syntax error, or upon pressing intentionally the RST key, the message "? REPEAT:" will appear and you can restart again. Once the desired number has been properly composed on display, it is entered by pressing the ENT/PRT key.

- Pressing simultaneously the keys 1,2 and 3 will cause a *reset* of the unit, equivalent to switching off and on again. This function is hard-wired and independent of software. It is also equivalent to pressing the *RESET button* at the back of the instrument.

D.1 STARTING UP

A) Switch ON the instrument or reset it either by pressing the RESET button located at the rear panel or by pressing simultaneously the keys 1, 2, and 3.

B) The text "VTC 90" appears and remains on display for about 5 seconds, unless you press one of the following keys (we will refer to this interval as the *reset interval*):

ENT/PRT will immediately terminate the 5-seconds wait and enter the temperature monitoring routine
0,1,2,... enter Program 0,1,2,... (if implemented).
CAL/PRG will invoke the SPECIAL PROCEDURES menu
RST followed by CAL/PRG will ask whether to switch over to the TD-MATE operating system (see the TROUBLE SHOOTING section).

Should anything else happen, please consult the TROUBLESHOOTING Section of this manual.

DURING THE RESET INTERVAL, THE MOST FREQUENTLY USED ACTIONS ARE:
- **Press nothing** Temperature monitoring starts within 5 seconds
- **Press ENT/PRT** Temperature monitoring starts immediately. Once you are within the temperature monitoring routine.
- **Press CAL/PRG** to enter the temperature control routine.

We will now describe in detail the following programs:
>> **Program 0** - Temperature monitoring.
>> **Program 1** - Temperature control.
>> **Program 2** - Power generator with temperature monitor.
>> **Special Procedures**.

D.2. TEMPERATURE MONITORING (PROGRAM 0)

Program 0 is the *default program*, recalled automatically after the *reset interval*, provided you do not press any key during. It can be also entered by pressing the *ENT/PRT* key or the *0* key (for Program 0) during the *reset interval*.

Once running, Program 0 will start *displaying the control channel temperature* in degrees Centigrade.

The displayed temperature will be correct only if the control channel sensor has been correctly configured (sensor type, reference type, reference temperature). For further details, see *"Reference" and "Channel Configuration" in the Special Operations Section*.
During monitoring, the sensor integrity is being continuously tested. If the sensor breaks down or becomes disconnected, the "interlock" light comes ON and the message *"BROKEN SENSOR"* appears repetitively until the condition ceases.

If a *second monitor channel* is also implemented and its sensor is operative and properly configured, its reading will automatically appear on the display. Should the sensor break down or be disconnected, this reading will simply disappear without any message.

If the optional printer is mounted, pressing the key *ENT/PRT* during monitoring will result in a printer copy of the current display.

By default, the monitoring routine displays the temperature with two decimal digits. Pressing the keys 0, 1, 2, or 3, however, you can *set the display format* to the corresponding number of decimal digits. In any case, the displayed values are properly rounded.

The *display repetition time* and the *noise averaging efficiency* depends upon the parameter NM (number of measurements per reading during monitoring); see the PARAMETERS EDITING section for further details. The control and monitor channels *sensor types* and the control channel reference mode depend upon the current sensor configuration (see the Sensor Configuration section). The displayed readings are automatically adjusted according to current *sensor calibration* parameters (see the Sensor Calibration section).

The monitoring will proceed until interrupted from the keyboard by pressing either the *RST* or the *CAL/PRG* key. In the first case, the system will be reset and the power-up procedure will restart. In the second case, the temperature controller program (Program 1) is entered.

D.3 TEMPERATURE CONTROL (PROGRAM 1)

There are two ways to enter the temperature controller program:
1. Enter the temperature monitoring routine and then press *CAL/PRG*
2. Press *1* (for Program 1) during *the reset interval*.

Before entering the temperature control program, check that:

i. All external parts of the system are functioning properly.

This means in particular:
- If liquid nitrogen evaporator is not used, the *carrier gas must be flowing* through the system (operation above room temperature) and, if required, is being properly pre-cooled (operation at and below room temperature).
- If liquid nitrogen evaporator is used, make sure that it is connected and that the *liquid nitrogen level* is high enough to submerge the heating resistor).

ii. The controller is properly configured.

This means that the correct *sensor type and reference type* for the control channel must be set. Moreover, a satisfactory operation requires a *proper set of control algorithm parameters*. Different set-ups require somewhat different parameters in order to optimize the controller performance. Proper values of the parameters are usually found empirically and stored in the non-volatile memory. In fact, several different sets (*parameter tables*) can be stored; subsequently, any one of them can be selected (see the *Load Parameters* procedure in the *Special Operations* section).

The control parameters include:

CP proportional coefficient
CI integral coefficient
CD derivative coefficient
SF set-point approach factor
FP filter-predictor factor
IB integral action band
IA integral approach damping factor
MP maximum heater output power
MS maximum step in output power
NR averaging number in regulation
LL set-point low limit
UL set-point high limit
LS safety low limit
US safety high limit
EV evaporator power level (or EV=0 for no evaporator)
FL carrier gas flow level
SO set-point offset
SS set-point scale

D.3.1 TEMPERATURE CONTROL WITHOUT EVAPORATOR (EV=0)

If the current configuration parameters are set for use without evaporator, the following things will happen when the temperature control program is entered:

i) The system will display the last used value of the carrier gas flow. You should either confirm it by pressing *ENT/PRT* or else introduce a new value. In the latter case, the message "WAIT!" will appear for a few seconds while the system is memorizing the new configuration. In any case, adjust the gas flow regulator to make the actual flow correspond to the value entered from the keyboard.

Warning: Carrier gas flow has a direct impact on the controller performance. Drastic variations in the flow level may require re-adjustment of other control algorithm parameters.

ii) The "heater" light switches ON and there is an audible click as the heater power output is enabled. Even though the heater is enabled, however, the heater output current is set to zero for safety reasons.

iii) The system will display the current sample temperature and wait for the introduction of the set-point (the display prompter may look like " 24.6 SET:_" ,where 24.6 is the current sample temperature and the cursor is flashing. Enter the desired set-point value comprised within the set-point range limits.

Please, proceed now to the section "Temperature Control: Operative Phase).

D.3.2 TEMPERATURE CONTROL WITH EVAPORATOR (EV>0)

If the current configuration parameters are set for evaporator, the following things will happen upon entry into the temperature control program:

i) The system will display the last value of the evaporator channel output power (in % of full range). You should either confirm it by pressing *ENT/PRT* or else introduce a new non-zero value. In the latter case, the message "WAIT !" will appear for a few seconds while the system is memorizing the new configuration.

***Warning*:** Evaporator power level has a direct impact on the controller performance. Drastic variations in the flow level may require re-adjustment of other control parameters.

ii) The "heater" and "evaporator" lights switch on and there is an audible click as the two power outputs are enabled. However, only the evaporator output is actually powered, the heater output currents is set to zero for safety reasons.

iii) The system will display the current sample temperature and wait for the introduction of the set-point just like in the previous case (see Ic).

D.3.3 TEMPERATURE CONTROL: OPERATIVE PHASE

The instrument now proceeds to the actual control consisting of correction "cycles" repeated about once a second. In each cycle, three numbers appear on the display: the actual temperature, the set-point, and the heater power level (in % of full range).

If the control parameters are reasonable, the system will reach the set-point and then stabilize in terms of both the temperature and the output power.

The following keys are operative in this phase:

RST Emulates a full reset of the instrument.

CAL/PRG Input a new set-point value while maintaining the output channel(s) power.

FRM/. When the monitor channel is available, toggles the display format between the two case listed below:

Case 1:	**ccc.c sss.s pp**
Case 2:	**ccc.c mmm.m C**
where	
ccc.c	is the control channel temperature,
sss.s	is the set-point temperature
mmm.m	is the monitor channel temperature
pp	is the heater power level
C	is the letter "C" indicating we are in Control.

+/- Input a new gas flow (if EV=0) or evaporator (if EV<>0) power level while maintaining the output power channel(s) active.

ENT/PRT If you have the optional printer, pressing ENT/PRT will result in a printer copy of the current display.

0,1,2,3 Set display to 0,1,2, or 3 decimal digits precision. Note: If the precision is more than 1 decimal digits, the display items indicated above as pp and R are not displayed for lack of space.

9 Calibrate the set-point while maintaining the output power level(s). The system will first display the query **"? S.P.CALIB."**
Press **ENT/PRT** to confirm it or **RST** to ignore it. For further details on the set-point calibration, see the Special Operations section.

D.4 POWER GENERATOR WITH TEMPERATURE MONITOR (PROGRAM 2)

This program can be entered only by pressing the key *2* during the reset interval. It displays the query *"? POWER SOURCE"* ;press *RST* (no) for immediate reset or *ENT/PRT* (yes) for confirmation.

In the latter case, Program 2 permits to set any one (or both) output channels to any value intended as a percentage of the full power range. The set-up dialog is the following:

Instrument	Operator
? HEATER	**RST** (no) or **ENT/PRT** (yes)
if yes: **%POWER**	Any desired value 0 - 100%
? EVAPORATOR	**RST** (no) or **ENT/PRT** (yes)
if yes: **%POWER**	Any desired value 0 - 100%

The instrument then enables the specified power channel(s), calculates and sets the current(s) corresponding to the specified power level(s), and proceeds to monitoring of the control channel and, if mounted, the monitor channel temperature(s) just as in Program 0. Once in operation, you can press any of the following keys:

RST Resets the instrument .
0,1,2,3 Change number of displayed decimal digits.

The formula used to set the currents is:

I(set) = SQR[I(max)(%Power)/100)],

where I(max) is the maximum available current (it can be trimmed separately for each channel as described in the Hardware Troubleshooting and Calibration section). Once set, the current is kept strictly constant by the circuitry independently of any load resistivity variations (the amperostat function), unless the maximum voltage specification is exceeded by applying an excessively resistive load (voltage output saturation). There is no problem with low resistivity loads - the output may be shorted without any problem and any variation in the current.

E. SPECIAL OPERATIONS

In order to enter the *Special Operations menu,* press *CAL/PRG* during the *reset interval*. A series of queries will be displayed, each corresponding to a special-routine option. You can select any option by pressing the *ENT/PRT* key (yes) in response to the respective query.

Vice versa, you can skip any option by pressing the *RST* key (no). If none of the selected options has been selected, the unit will return to the reset interval.

THE SPECIAL OPERATIONS MENU INCLUDES:

? INFORMATION	Display info about the current set-up.
? REFERENCE	Set the reference junction parameters.
? CNTRL PARAM.	Edit control algorithm parameters.
? COPY PARAM.	Copy current control parameters table.
? JOIN PARAM.	Join another control parameters table.
? SNSR CALIB.	Calibrate one of the available sensors.
? S.P. CALIB.	Calibrate the Set-Point.
? CHNL CONFIG.	Configurate a sensor channel.
? RS232 CODE	Configurate the serial interface

We will now describe the individual options in detail.

E.1 SPECIAL OPERATION: INFORMATION

This option is used to check current-configuration data such as the active control-parameters table, configuration of sensors, etc. It does not require any input and does not modify any of the displayed parameters (there are other ways to modify some of them). The info items are displayed one by one, in the format consisting of a short name (acronym) followed by the current value. You must hit any key to proceed to the next one. The following items are displayed:

VRSN Firmware version number in the format YYMM.R, where YYMM.V, where YY denotes the year, MM month, and R the revision number.

TBL Currently active control parameters table.

There may be several parameter tables stored in the non-volatile memory. Each table may correspond to a different thermal load and/or different range of temperature. The distinction between using or not using the optional evaporator is also stored in the table. For more details, see CONTROL PARAMETERS section.

REF Type of reference employed in the control channel.
0 indicates the compensated reference junction, while
1 denotes a true reference TC.

CSNS Control sensor type.
The currently implemented sensor types are:
0 millivoltmeter, using any transducer
1 Cromel-Alumel
2 Iron-Constantan
3 Copper-Constantan

RT Reference temperature.
This item will appear only if REF=1 (true reference junction) and indicates the temperature (in °C) of the reference junction bath. RT can be changed by means of the special operations option REFERENCE T (see below).

CSCL The scale calibration coefficient for the control channel sensor. It is normally set by the two-point sensor calibration procedure. It can also be set manually within the sensor configuration procedure. Its default value is 4.0439 for the compensated reference mode and 4.08 for the true reference junction mode.

COFF The offset calibration coefficient for the control channel sensor. It is normally set by the one or two-point sensor calibration procedure. It can also be set manually within

the sensor configuration procedure. Its default value is -.0109 for the compensated reference junction mode and 0 for the true reference junction.

MSNS Monitor sensor type (analogous to CSNS).

MSCALE The scale calibration coefficient for the control monitor sensor (analogous to CSCALE).

MOFF The offset calibration coefficient for the control monitor sensor (analogous to COFFS).

E.2 SPECIAL OPERATION: REFERENCE JUNCTION PARAMETERS

This option regards only the control channel. It is used to change the reference junction mode without having to go through the full channel configuration routine. In the case of a true reference junction TC, it also allows to set the actual reference junction temperature.

The system will first display the query *"? COMPENSATED"*. Press *ENT/PRT* if you want to confirm the compensated reference junction mode an *RST* otherwise. In the first case, you have finished and the instrument will reset.

In the second case, the query "? REFERENCE TC" will appear. If you press *RST* (no), there will be a reset with nothing done. If you confirm the mode by pressing *ENT/PRT*, however, the prompter *"RT rrr.tttt"* will appear, where rrr.tttt is the currently set reference junction temperature. You may either confirm it by pressing *ENT/PRT* or else input a new value.

RT indicates the temperature (in ^{o}C) of the reference junction bath. You can use any suitable reference bath such as melting ice (RT=0), boiling water (RT=100), freely evaporating liquid nitrogen, melting gold, etc.

E.3 SPECIAL OPERATION: CONTROL PARAMETERS EDITING

This option permits to *check and/or edit* the currently active control parameters table. Before proceeding, you should take into account the following facts:

a. Control parameters include all numeric parameters pertinent for the temperature control operation. On the other hand, they do not include numeric parameters pertinent to simple temperature measurements such as sensor configuration and calibration data.

b. The control parameters may differ from case to case according to the carrier gas (for example external room-temperature or precooled source, or nitrogen from a liquid nitrogen evaporator) and according to the particular thermal load (e.g.,a probehead) and the desired temperature range (at -100 ^{o} the parameters are likely to be somewhat different than at +150^{o}). As a consequence,
The instrument therefore permits to create and edit distinctly numbered *control parameters tables*. Using the special operation "JOIN PARAMETERS" (see below), any one of the existing tables may be selected as the 'active' one. The "EDIT PARAMETERS" procedure permits to check and/or modify the parameters in the 'active' table. A duplicate of the current 'active' table can be made by means of the special operation "COPY PARAMETERS". These three procedures allow a simple but effective management of the stored control parameter tables.

c. Upon exit from the editing procedure, the (presumably) modified table will be stored in the non-volatile memory. The currently 'active' table is automatically recalled upon switching on or resetting the instrument ensuring a continuity between consecutive intervals of use.

THE CONTROL PARAMETERS EDITING PROCEDURE:

For each system parameter, its acronym and its current value are displayed. Press ENT/PRT to confirm the current value, or input a new one. When the list of parameters is exhausted, the system save them (this can take a few seconds) and resets. If you have the optional printer, a list of all parameters will be generated.

THE FOLLOWING PARAMETERS ARE CURRENTLY SUPPORTED:

NAME **DESCRIPTION**

CP **PROPORTIONAL TERM COEFFICIENT.**
It is expressed as the percentage of output power for one degree of deviation from the set-point.
Recommended values: 0.5-2 (Proportional) or 10000 (ON/OFF)
Admissible values : any non-negative number

CI **INTEGRAL TERM COEFFICIENT.**
It is also intended as the percentage of output power per one degree variation of the deviation integral.
Recommended values: 0.5-2
Admissible values : any non-negative number

CD **DERIVATIVE TERM COEFFICIENT.**
Percentage of output power for one degree variation between two consecutive measurements. It is used to damp excessively fast temperature variations and therefore decrease overshoots (damping).
Recommended values: 0.2-5
Admissible values : any nonnegative number

SF **SET-POINT APPROACH FACTOR.**
In most VT controllers, whenever the set point changes, the new value is immediately presented to the control algorithm. The VTC91, however, changes the 'operative' value of the set point gradually, starting at the current temperature and terminating at the desired set point. In each control cycle, the difference between the final and the 'operative' set point values is reduced by the factor SF. The setting SF=0 corresponds to the traditional behaviour.
Recommended values: .90-.97
Admissible values : 0-.999

FP **FILTER/PREDICTOR FACTOR FOR THE MAIN SIGNAL INPUT.**
For **FP>1**, a linear predictive action is introduced. This may dramatically increase stability in highly-dynamic thermal systems since it tends to compensate the phase lag between the control action (power output) and its effect (sensor temperature). With most thermal loads, the phase-lag is quite large and causes most of the temperature control problems.

Putting **FP=1**, the input values are left unchanged.
For **FP<1**, a filtering action analogous to a one-pole RC filter is introduced. For example, if the control cycle time is 1 sec, and FP=0.1, the result is identical to applying an RC filter with time constant of 10 sec to the input. This will reduce system noise but, on the other hand, increase the deleterious phase-lag described above.

Recommended values: 1.0-1.5
Admissible values : >0.01

IB **INTEGRAL ACTION BAND.**
The integral term increment is given by the following formula:
CI * {D/[1+(D/IB)^2]} ,
where D is the measured deviation from the set-point. For values of D substantially smaller than IB, this is approximately equal to CI*D. With increasing D,a maximum of D/2 is reached for D=IB and then a rather fast decrease occurs (we speak about integral action neutralization). It prevents the integral term from becoming excessively large before the set point is reached - a situation which would lead to a large overshoot. For example if IB=10 and D=30, then the increment is only 3, rather than the 30 one would expect with no integral action neutralization.
Recommended values: 5-20
Admissible values : any non-negative number

IA **PREDICTIVE INTEGRAL APPROACH DAMPING.**
When this term is absent (value zero), the integral term is quite inefficient to damp any small oscillation around the set-point. In order to damp these oscillations, the integral term build-up must be interrupted (no increment) if the signal derivative indicates than, using the current value of integral, the set-point is to be reached anyway in less than IA steps. Setting IA very large (any value above about 100 will have the same effect) is equivalent to interrupting the integral term build-up whenever an excursion cycle reaches a maximum (zero derivative). It is very efficient in quenching oscillations but may lead to sluggish behaviour during an overdamped approach phase.
Recommended values: 20-80
Admissible values : any non-negative number

MP **MAXIMUM OUTPUT POWER (IN % OF FULL RANGE).**
MP may be used as a safety precaution in those situation where you know a-priori that only a fraction of the output power will be needed.
Admissible values: 0-100

MS **MAXIMUM OUTPUT POWER STEP (IN % OF RANGE).**
The output power may not change by more than MS% in a single control cycle. Putting MS very low (e.g. 0.25) makes the approach phase rather slow but reduces the overshoot. Putting MS=100, its effect is completely eliminated. Values of at least 10 are required in high-dynamics systems if fast action with minimum overshoot is required. Experience shows that, apparently paradoxically, in such systems reducing the value of MS to an intermediate level (1-5) often increases the overshoot.
Recommended values: 5-100 or 0.05-0.5
Admissible values : any positive number

NR **AVERAGING NUMBER FOR TEMPERATURE CONTROL (REGULATION).**
NR specifies the number of elementary measurements which are to be averaged before the result is displayed (measurements per reading). Each elementary measurement requires about 15m sec (including self calibration) and has a nominal precision better than 0.01 °C. Increasing NR increases the nominal precision proportionally to the square root of NR but, at the same time, slows-down the regulation cycle repetition rate and thus increases the undesired phase-lag (see the description of FP).
Recommended values: 4-20
Admissible values : positive integers

NM **AVERAGING NUMBER FOR TEMPERATURE MONITORING.**
This parameter is similar to NR described above, but applies to any temperature readings outside the temperature control routine. In this case, the software overhead less time consuming and substantially larger numbers can be used while maintaining a reasonable reading refresh time. Note that due to the averaging, the first measurement after a drastic change in conditions may be wrong.
Recommended values: 20-100
Admissible values : positive integers

LL **LOWER SET-POINT LIMIT IN DEGREES CENTIGRADE.**
It may be desirable for safety reasons to make it impossible to introduce, not even by a mistype, an unreasonable value of the set-point. For this reason, two set-point limits, low and high, can be specified by the user.
Admissible values : any number

UL **UPPER SET-POINT LIMIT IN DEGREES CENTIGRADE.**
See LL for more details.
Admissible values : any value higher than LL

LS **LOWER SAFETY LIMIT IN DEGREES CENTIGRADE.**
For major safety, the user may specify two safety interlock limits: LS (low) and HS (high). If, for any reason, the control channel temperature exceeds US or drops below LS, both output power channels are disabled and a proper message is displayed (either "TEMP TOO LOW" or "TEMP TOO HIGH").
Recommended values: LL-20
Admissible values : <=LL

US **UPPER SAFETY LIMITS IN DEGREES CENTIGRADE.**
See LS for more details.
Recommended values: UL+20
Admissible values : >=UL

EV **EVAPORATOR OUTPUT POWER IN % OF FULL RANGE.**
Apart from specifying the power applied to the nitrogen boil-off resistors in the liquid-nitrogen evaporator, this parameter is used as a flag whether the evaporator is actually used (EV>0) or whether an external carrier gas flow is being applied.
Admissible values : 0-100

FL **CARRIER GAS FLOW LEVEL.**
This parameter is meaningful only if EV>0. Since the gas flow regulator is manual, FL serves only as a reminder about the flow level that should be set by the operator (and for which the parameters table has been presumably optimized).
Admissible values : any number

SO **SET-POINT OFFSET.**
This parameter is normally set-up by the set-point calibration routine and should not be changed manually unless there are good reasons for it. Its default value is 0 (by entering a zero you can in fact cancel the effect of a set-point calibration. For more details, see the Set-Point Calibration section.
Admissible values : any number.

SS **SET-POINT SCALE.**

This parameter is normally set-up by the set-point calibration routine and should not be changed manually unless there are good reasons for it. Its default value is 1 (by entering 1.0 you can in fact cancel the effect of a set-point calibration. For more details, see the Set-Point Calibration section.
Admissible values : any positive number.

E.4 SPECIAL OPERATION: COPY A PARAMETERS TABLE

For the purposes explained above, the instrument permits to create and edit distinctly numbered *control parameters tables*. The "COPY PARAMETERS" procedure creates a copy of the currently 'active' table. It displays the message *"SV TAB n"* where n is the number of the currently active table. At this point you must input the number of the table into which the current parameters should be written. Once you have input an admissible value (admissible values range from 1 to 6), the message *"WAIT"* will appear and subsequently two different things may happen:

1. The message *"ERR:REG"* will appear if there is not enough reserved, non-volatile memory for the specified table number. In this case, reset the instrument; you will find its configuration unchanged as though nothing happened. You may try again with a lower table number (usually, space for at least 5 tables is reserved).

2. The message "WAIT" disappears after a few seconds and the instrument resets itself automatically. In this case the operation succeeded. Moreover, the new table has been automatically *JOINED* so that it is now the active one and you can, if you wish, proceed to editing its parameters.

Warning: The "COPY PARAMETERS" procedure does not test whether the specified table already contains valid parameters. If so, they are replaced by the new ones without any warning.

Note: It is allowed to copy a parameters table into itself; no harm results but, of course, nothing useful is done is this case.

E.5 SPECIAL OPERATION: JOIN A PARAMETERS TABLE

This option permits to 'join' or, in other words, to 'activate' a desired parameters table. The operation is extremely simple. First, the instrument displays the message *"LD TAB n"* where n is the number of the currently active table. At this point you must input the number of the table which you want to join. If the table exists, the instrument will make it active and reset itself. Otherwise a message *"MISSING TABLE"* will appear; pressing any key leads to a reset with the original configuration left intact.

E.6 SPECIAL OPERATION: SENSOR CALIBRATION

The sensor calibration procedure permits to *correct the offset and gain of the sensor-transducer combination (STC)* in any channel. Three pairs of parameters are in fact maintained: one for the monitor channel and two for the control channel where the two reference modes (compensated/true reference TC) are considered as distinct (distinct hardware is in fact used). The sensor calibration, as opposed to the set-point calibration (see below), regards the static performance of the instrument when used as a thermometer. *Its purpose is to make the measured temperature correspond as closely as possible to the actual temperature at the tip of the sensor.* One-point and two-point calibrations are possible; the one-point calibration corrects only the voltage offset of the STC, while the two-point calibration corrects also the gain factor.

As soon as you enter into the Sensor Calibration routine, the query *"? CNTRL CHNL"* will appear. Press *ENT/PRT* if you want to calibrate the control channel or *RST* if not. In the latter case, the query *"?MONIT CHNL"* will appear. Confirm the monitor channel calibration by pressing *ENT/PRT* or reset the instrument by pressing *RST*.

Keep in mind that if you select the control channel, the calibration will regard only the currently configured reference junction mode.

Once the channel has been chosen, the query "? ONE POINT" will appear. Press ENT/PRT to confirm one-point calibration or RST to execute the two-point calibration.

1. ONE-POINT SENSOR CALIBRATION.

- In this case the message "MEASURE !" will appear.
- Prepare your calibration device (iced water bath or whatever), set-up the sensor, and press any key.
- The instrument will start monitoring the sensor temperature. When you see that it stabilized, press ENT/PRT (you can also press RST to reset the instrument with nothing done).
- At this point the last-measured value is memorized and the prompter "TRUE VALUE =" will appear.
- Input the correct temperature of the sensor.
- The message "WAIT" will appear and remain on display for some time (about 1 minute); after that the instrument will reset itself and the calibration is done.

1. TWO-POINT SENSOR CALIBRATION.

- In this case the message *"1ST MEASURE !"* will appear.
- Prepare your first-point calibration device (e.g., iced water bath), set-up the sensor, and press any key.
- The instrument will start monitoring the sensor temperature. When you see that it stabilized, press ENT/PRT (you can also press RST to reset the instrument with nothing done).
- At this point the last-measured value is memorized and the prompter "TRUE VALUE =" will appear.
- Input the correct temperature of the sensor.
- The message "WAIT" will appear and remain on display for some time (about 1 minute).
- The message "2ND MEASURE !" will appear.
- Prepare your second-point calibration device (e.g., boiling water bath), set-up the sensor, and press any key.
- The instrument will start monitoring the sensor temperature. When you see that it stabilized, press ENT/PRT (you can also press RST to reset the instrument with nothing done).
- At this point the last-measured value is memorized and the prompter "TRUE VALUE =" will appear.
- Input the correct temperature of the sensor.
- The message "WAIT" will appear and remain on display for some time (about 1 minute); after that the instrument will reset itself and the calibration is done.

When the calibration is finished, you can use the INFORMATION option to check the variations in scale and/or offset caused by the calibration. You can also void any calibration by restoring the default scale and offset of the transducer using the CHANNEL CONFIGURATION option.

E.7 SPECIAL OPERATION: SET POINT CALIBRATION

The set-point calibration procedure permits to *apply a linear correction of the sample temperature as opposed to the control channel sensor temperature.*

In any practical control set-up there is a fundamental problem: what is actually controlled is the temperature of the *tip of the sensor* rather than that of the sample !!! The difference can be made small if proper precautions are taken, but it is never zero.
Usually it is much larger than both the precision of the instrument and the inherent stability of the control loop. In other words, the controlled temperature may be very stable but, at the same time, quite incorrect.
In arrangements characterized by severe geometrical constraints and conflicts with other devices (examples: NMR probeheads or EPR cavities), the difference can easily reach several degrees. When using room temperature carrier gas, it is always negative (i.e., the sample temperature is lower than the set-point). When the carrier gas temperature is below the room temperature, however, the difference may be both positive and negative. It decreases with increasing carrier gas flow; however, differences inferior to 1^{o}C are difficult to obtain. The carrier gas flow values required to reduce the difference below a tolerable level are often severely exaggerated from other points of view (temperature stability, heater power, heat transfer efficiency, carrier gas consumption, etc.)

In many techniques, there are additional other sources of discrepancy. A typical example is the heat generated directly inside an NMR sample tube by dielectric losses when high-power RF irradiation (decoupler) is used.

The only practical solution to this problem is an empirical calibration using independent measurements of the sample temperature as a function of the set point. We have found such calibration curves to be quite linear over a wide range of temperatures, provided that

other conditions are maintained constant (in particular the carrier gas flow and, in NMR, the decoupler power).

In practice, you will have to measure the sample temperature during the temperature control. This can be done, for example, by inserting the monitor channel thermocouple directly into a sample phantom. However, you can also use any other thermometric device or even any temperature-dependent characteristic of the sample (e.g., in NMR you can find out the actual sample temperature from the spectra of a suitable substance such as ethyl- or methyl- alcohol). You will need one pair of [set-point, true sample temperature] for a one-point calibration and two such pairs (possibly close to the limits of the interval of interest) for a two-point calibration.

The one-point calibration corrects only the calibration curve offset at the specific temperature. However, whenever there is a significant difference, the scale of the calibration curve is also significant. We therefore recommend to use always the two- point calibration procedure.
There are two ways to execute the set-point calibration. It can be done outside the control program or even during the temperature control. The latter possibility, invoked by pressing the digit **9** key (see Program 1), is sometimes very handy. Just keep in mind that the power outputs are kept at a constant level but no active temperature control is being done while the calibration is in progress. Therefore, you should enter the routine only after reaching a steady state.

Whatever is the mode to invoke it, the routine will first present the query *"? ONE POINT"*. Press *ENT/PRT* to confirm the one-point calibration modality or *RST* to negate it. In the latter case, the query *"? TWO POINTS"* will be displayed and you may confirm it as usual by pressing the *ENT/PRT* key. At this point, if you press *RST*, the system will reset with nothing done.

1. ONE-POINT SP CALIBRATION.

- In this case the message *"SET VALUE ="* will appear.
- Input the set-point value used during the measurement.
- The message *"TRUE VALUE ="* will appear.
- Input the measured sample temperature.
- The instrument will reset and the calibration is done.

1. TWO-POINT CALIBRATION.

- In this case the message *"SET T1="* will appear.
- Input the set-point value used during the first measurement.
- The message *"TRUE VALUE ="* will appear.
- Input the corresponding, measured sample temperature.
- The message *"SET T2="* will now appear.
- Input the set-point value used during the second measurement.
- The message *"TRUE VALUE ="* will appear.
- Input the corresponding, measured sample temperature.
- The instrument will reset and the calibration is done.

The parameter modified by the Set-Point Calibration routine are SO (set-point offset) and SS (set-point scale) within the *currently active* control parameters table. Thus, each control parameters table may have a distinct calibration setting.

E.8 SPECIAL OPERATION: CHANNEL CONFIGURATION

If you change a sensor with a different type, you must also change the corresponding sensor code. Similarly, if you change the reference junction mode (compensated/true reference TC), the system must be properly re-configured. All this is done using the Channel Configuration option.

This option also permits to set/reset the sensor calibration parameters (offset and gain).

The procedure is self-explanatory in the sense that it guides the operator with proper queries and prompters. We will illustrate it by a few examples.

Example A. Control channel
Reference junction compensation.
Copper-Constantan thermocouple.
Default offset and gain.

Operator input	Consequent VTC actions	
	? CNTRL CHNL	Select control/monitor chnl
ENT	? COMPENSATED	Select compensation mode
ENT	? 3 CU-CONST.	Select sensor type
ENT	OF -0.0109	Defaults for compensated
ENT	SG 4.0439	reference junction.
ENT	VTC 90	Finished

Example B. Control channel
True reference junction.
Chromel-Alumel thermocouple.
Default transducer offset and gain.

Operator input	Consequent VTC actions	
	? CNTRL CHNL	Select control/monitor chnl
ENT	? COMPENSATED	Select compensation mode
RESET	? 3 CU-CONST.	Select sensor type
RESET	? 2 FE-CONST.	
RESET	? 1 CR-ALUMEL	
ENT	OF 0	Defaults for true
ENT	SG 4.0800	reference junction.
ENT	VTC 90	Finished

Note: If the differential transducer for true reference junction arrangement is not implemented on your unit and you erroneously configure the control channel as though it were available, the unit will signal ***"BROKEN SENSOR"*** as soon as you enter the monitoring or controller routine. In this case, the only thing to do is to reset and re-configurate the channel reference mode to make it compatible with the hardware.

Example C. Control channel
Reference junction compensation.

Copper-Constantan thermocouple.
Offset and gain taken from a previous calibration.

Operator input	Consequent VTC actions	
	? CNTRL CHNL	Select control/monitor chnl
ENT	? COMPENSATED	Select compensation mode
ENT	? 3 CU-CONST.	Select sensor type
ENT	OF -0.0109	Override the defaults:
-0.0157		(an example)
ENT	SG 4.0439	
4.0207		(an example)
ENT	VTC 90	Finished

Example D. Monitor channel
Chromel-Alumel thermocouple.
Default transducer offset and gain.

Operator input	Consequent VTC actions	
	? CNTRL CHNL	Select control/monitor chnl
RESET	? MONIT CHNL	Confirm monitor
ENT	? 3 CU-CONST.	Sensor type selection
RESET	? 2 FE-CONST.	
RESET	? 1 CR-ALUMEL	
ENT	OF 0	Defaults for true
ENT	SG 4.0800	reference junction
ENT	VTC 90	Finished

Note that in the case of monitor channel, only the compensated reference junction mode is available.

F. HARDWARE DESCRIPTION

(reference drawing: REAR VIEW OF PARTS)

In this section we describe the internal composition of the instrument's hardware at the level of boards. It is essentially intended as a guide for the following Hardware Calibration section.

THE SYSTEM IS COMPOSED OF THE FOLLOWING BOARDS:

- ✔ **POWER_SUPPLY** board provides the DC voltages of + 5 and +/- 15 for the whole unit. *Note that every voltage output has a separate fuse.*

- ✔ **CPU board** with EPROM, RAM, and EEPROM memory.
  Occasionally, new application software may become available. This resides (and is distributed) in an EPROM chip. There are two EPROM chips mounted on the board one on top of the other (piggyback arrangement). Since the two 24-pin chips have all the pins but one in common, the lower one has a 24 pin socket soldered to it. EPROM exchange consists of dissoldering the conductor connected to the single non-shared pin (#20), taking the upper EPROM out of the socket, replacing it with the new one (be

careful to orient it the same way as the lower one and to leave its pin 20 free), and connection to its pin 20.

- ✔ **AD_16_BIT** board is a 16-bit, single-slope Analog-to-Digital converter with a sampling rate of over 200 Hz. Three *trimmers P1, P2, and P3* are available for the calibration of scale, offset, and voltage reference, respectively.
  (see the Hardware Calibration section).

- ✔ **4CH_DAC** is a four channel Digital-to-Analog converter board. Two channels are used to generate the reference voltages for the Evaporator Power Driver and Heater Power Driver boards.
  The offsets of these reference sources can be corrected by the *trimmers P2 and P3*, respectively (see the Hardware Calibration section).

- ✔ **The VT_INPUT** board implements the analog multiplexer between the different measuring channels and the hardware interlocks. *Trimmers P1 e P2* permit to adjust the thresholds of the safety interlocks for the evaporator and the heater, respectively (see the Hardware Calibration section).

- ✔ **RS_232** is an optional interface with a host computer.

- ✔ **TC_ADAPTER board** containing two TC transducers AD595 with electronic reference junction compensation, used for TC1 and TC2 inputs, and one precision OP-amp transducer used with TC3 and TC REF inputs. In order to minimize transducer drifts (room temperature dependence), all active parts are placed in a thermostated oven.

- ✔ **VTCON board** : this board implements all interlocks, alarm and control signals between the unit and the **VT_INPUT** board.

- ✔ **HEATER POWER DRIVER** supplies the heater resistor with a DC current proportional to a reference voltage signal generated by the *4CH_DAC_BOARD*. The ratio between the output current and the reference voltage can by set by *trimmer P1* (see the Hardware Calibration section).

- ✔ **EVAPORATOR POWER DRIVER** supplies the evaporator resistor with a DC current proportional to a reference voltage signal generated by the *4CH_DAC_BOARD*. The ratio between the output current and the reference voltage can by set by the *trimmer P1* of the latter board (see the Hardware Calibration section).

G. HARDWARE CALIBRATION

Before delivery, all necessary calibrations are made in factory so you do not need to do them at installation. Before making any hardware calibration, please read the section Hardware Description and refer to drawing **REAR VIEW OF PARTS**.

HEATER POWER CALIBRATION:

The purpose of the calibration is to achieve maximum power transfer by properly changing the transconductance of the HEATER POWER DRIVER board (i.e., the ratio between the output current and the reference voltage voltage generated by the **4CH_DAC** board). The proper setting depends upon the resistance of the heater wire. If the heater is supplied by Stelar, the heater will be already calibrated; otherwise, you will have to do it yourself in order not to downgrade the unit's performance.

Note: Best power performance is achieved with 8 Ohm heater resistors. Values from 4 to 16 Ohm are acceptable even though they will not permit to exploit the full range of the power driver.

a) Open the left rear panel left and connect with care a DC voltmeter across the heater resistor (pins (1,2) and (4,5) of the HEATER connector).
b) Calibrate the heater current offset (zero current):
- Run Program #2 (see the Standard operations section).
- Select the heater and set %POWER = 0
- Using a screwdriver, turn trimmer **P4** on 4CH_DAC board until your voltmeter indicates 0 volt on the heating resistor.
- Reset the instrument.

c) Calibrate maximum heater current:
- make sure the heating resistance is immersed in a strong current of a carrier gas.
- Re-enter Program #2.
- Select the heater and set %POWER = 100.
- Using a screwdriver, turn trimmer P1 on the HEATER POWER DRIVER board until you see same voltage variation across the heater. Now keep turning P1 in the direction of increasing voltage. At some point you will either reach the end of the trimmer range (low heater resistance) or else the voltage will stop increasing because of saturation (high heater resistance). In any case, set the trimmer just below the maximum voltage limit.

EVAPORATOR POWER CALIBRATION:

The purpose of the calibration is to achieve maximum power transfer by properly changing the transconductance of the EVAPORATOR POWER DRIVER board (i.e., the ratio between the output current and the reference voltage voltage generated by the **4CH_DAC** board). The proper setting depends upon the resistance of the evaporator load. If the evaporator is supplied by Stelar, the calibration will be already done; otherwise, you will have to do it yourself in order not to downgrade the unit's performance.

Note: Best power performance is achieved with 8 Ohm evaporator resistors. Values from 4 to 16 Ohm are acceptable even though they will not permit to exploit the full range of the power driver.

a) Open the left rear panel left and connect with care a DC voltmeter across the evaporator resistor (pins (1,2) and (4,5) of the EVAPORATOR connector).
b) Calibrate the evaporator current offset (zero current):
- Run Program #2 (see the Standard operations section).
- Select the evaporator and set %POWER = 0

- Using a screwdriver, turn trimmer P2 on 4CH_DAC board until your voltmeter indicates 0 volt on the heating resistor.
- Reset the instrument.

c) Calibrate maximum evaporator current:
- make sure the evaporator rod is immersed in liquid nitrogen.
- Re-enter Program #2.
- Select the evaporator and set %POWER = 100.
- Using a screwdriver, turn trimmer P1 on the EVAPORATOR POWER DRIVER board until you see same voltage variation. Now keep turning P1 in the direction of increasing voltage. At some point you will either reach the end of the trimmer range (low evaporator resistance) or else the voltage will stop increasing because of saturation (high evaporator resistance). In any case, set the trimmer just below the maximum voltage limit.

CALIBRATION OF THE HEATER SAFETY THRESHOLD

The heater assembly contains a safety thermocouple. A hardware interlock connected with this TC detects a "SAFETY TC HOT" condition. It is essentially used to prevent overheating of the heater assembly in case of missing gas flow (e.g., due to a disconnected tube).

The purpose of this calibration is to set the safety TC threshold to a reasonable value.

There are two alternative ways to calibrate the threshold:

a) - Make sure that interlocks are off (the lamp "INTERLOCK" on the front panel must not be lighted).
- Disconnect the heater.
- Open the left rear panel.
- Find out from standard tables the thermocouple voltage corresponding to the desired safety threshold. You will need to know the type of thermocouple employed.
- Using an external voltage source, apply the above voltage to across pins 3(+) and 6(-) of the HEATER connector.
- Using a screwdriver turn trimmer P2 on the VT_INPUT board until locating the position around which the interlock lamp on the front panel switches on and off.

b) - Put the safety thermocouple at the desired threshold temperature.
- Open the left rear panel.
- Using a screwdriver, turn trimmer P2 on the VT_INPUT board until locating the position around which the interlock lamp on the front panel switches on and off.

CALIBRATION OF THE EVAPORATOR SAFETY THRESHOLD

The evaporator assembly contains a safety thermocouple. A hardware interlock connected with this TC detects a "MISSING N2" condition. It is essentially used to prevent operation if all liquid nitrogen has been boiled off and the heater is no longer immersed.

The purpose of this calibration is to set the safety TC threshold to a reasonable value.

There are two alternative ways to calibrate the threshold:

a) - Make sure that interlocks are off (the lamp "INTERLOCK" on the front panel must not be lighted).
- Disconnect the evaporator.
- Open the left rear panel.
- Find out from standard tables the thermocouple voltage corresponding to the desired safety threshold. You will need to know the type of thermocouple employed. Stelar uses

normally Copper-constantan TC's but other manufactures of the heater assembly may use different types.
- Using an external voltage source, apply the above voltage to across pins 3(+) and 6(-) of the EVAPORATOR connector.
- Using a screwdriver turn trimmer P1 on the VT_INPUT board until locating the position around which the interlock lamp on the front panel switches on and off.

b) - Put the safety thermocouple at the desired threshold temperature.
- Open the left rear panel.
- Using a screwdriver, turn trimmer P1 on the VT_INPUT board until locating the position around which the interlock lamp on the front panel switches on and off.

CALIBRATION OF THE 16 BIT ADC

The A/D converter needs to be calibrated only when the error message **GND:TARA** or **REF:TARA** is displayed.

In such a situation, proceed as follows:

VTC Display	Press	Comment
GND:TARA or RIF:TARA	ENT	Enter the diagnostic program
GAIN 0	ENT	Selects Gain setting
MPX 0	ENT	Selects Input Multiplexer
0G 0M 32768	RST	The number 32768 is only an example; it represents the ADC count for input 0
A .027 B .210	The numbers A and B are two calibration parameters for ADC.	

- Open the left rear panel.
- Use the trimmers P1 and P2 of the ADC_16_BIT board to set the numbers A and B to about 0.000. For a satisfactory calibration, A and B should fall within -.010 and +.010. If the calibration is impossible or if either A or B becomes .*** (overflow), the ADC board has a hardware failure.

H TROUBLESHOOTING

The controller, being based on the Stelar TD-MATE (Transducer Mate) operating system, is in principle a user-programmable general-purpose acquisition computer. To exploit this feature, you need the optional TD-MATE programming kit and manual.

H.1 HARDWARE PROBLEMS

However, a number of special tasks can be carried out without any special knowledge of the TD-MATE programming capabilities. These include in particular the ADC calibration and the instrument re- configuration after a serious system breakdown. Just follow the instructions without much bothering about the underlying reasons for what you are doing.
Whenever an anomalous behaviour occurs, first switch OFF the unit and then switch it ON again. This will reset all the interlocks.
If the message VTC 90 does not appear, switch OFF the unit and then switch it ON keeping RESET key pressed and proceed for full re-programming. (see paragraph H.3.).

H.2 LIST OF ERROR MESSAGES

1 - BROKEN SENSOR	Control TC not connected or broken.
2 - MISSING SENSOR	Monitor TC not connected or broken.
3 - MISSING AIR	The flowmeter doesn’t detect any gas flow.
4 - MISSING N2	The evaporator safety TC is too hot. (See HARDWARE CALIBRATION.)
5 - SAFETY TC HOT	The heater safety TC is too hot. (see: HARDWARE CALIBRATION)
6 - TEMP TOO HIGH	Verify parameter "US " (see: CONTROL PARAMETERS EDITING)
7 - TEMP TOO LOW	Verify parameter " LS " (see: CONTROL PARAMETERS EDITING)
8 - MISSING TABLE	TSpecified parameters table doesn't exist. (see section E.4)
9 - DIR.KO	Stored parameters are corrupted, you must reprogram the unit. (see: TROUBLESHOOTING , SOFTWARE PROBLEMS)
10- GND: TARA	The A/D converter must be calibrated (see: HARDWARE CALIBRATION)
11- RIF: TARA	The A/D converter must be calibrated (see: HARDWARE CALIBRATION)
12- GND: INST	The AD 16 BIT board has a hardware failure.
13- RIF: TARA	The AD 16 BIT board has a hardware failure

H.3 SOFTWARE PROBLEMS AND FULL RE-PROGRAMMING

If, upon switching ON or upon a CPU reset, the message "DIRECTORY KO" appears, than the EEPROM memory has been corrupted. In this case, you must reprogram it from scratch.

For full re-programming, proceed as follows:

VTC	User	Comment
CPU RESET		
DIRECTORY KO		If anything else happens, proceed
TABULA RASA		as described on next page
STOP !		
PRG0>		
	ENT	Directory program introduction:
0>		
	84	Introduce initialization code
VALUE:		
	2645	for LH71 display. If you have the LH2012 display, use 2644. If your CPU clock is 2,5MHz, use 2635 or 2634, respectively.
7>		
	12	Initialization command
8>		
	19	Return command
9>		

	-1	End of directory program
NUMBER OF REG.		
	640	Number of directory register (if EPROM is only 2Kbye, set 145)
	ENT	33 is minimum
NUMBER OF REG. 640		
	ENT	
DAC TYPE (0-1)		
	0	Standard 12bit DACs; 1 for 16bit
	ENT	
VR FACTOR	1	Voltage scale-down ratio (2 for high-temperature INPUT board)
	ENT	
VTC 90		
	CAL/PRG	Enter SPECIAL PROCEDURES
? PARAMETERS		
	ENT	Now modify any parameters according to Paragraph E.3.

At this point everything should be working again correctly.

It might also happen that, upon switching on, the following series of messages might occur: "DIR KO" followed by "TABULA RASA"
In this case, press ENT/PRT for confirmation; the system will arrive automatically to the point where the message "PRG0>" appears (see above). From this point on, the re-programming proceeds as described above.

VTC	User	Comment
STELAR PRODUCT		
	RST	Press RST before display changes
PROGRAM:OS907		The version number may differ.
? TESTS		
	RST	
? PROGRAMMING		
	ENT	
? ACCESS CODE		
	?	Input the last secret access code Units are delivered with A.C. 0.
? NEW FILE		If "? NEW FILE" does not occur the A.C. was wrong.
	RST	Not a new file
? ERASE FILE		
	RST	No file erasure
? MODIFY REG.		
	RST	Not a register modification
? FILE DUPLIC.		
	RST	Not a file duplication
? TABULA RASA		
	ENT	
		Clear all EEPROM memory
TABULA RASA		(forced TABULA RASA)
	ENT	Confirmation
STOP !		
PRG0>		From this point you proceed as described above.

H.4 FUSES

MAINS	: 2 A.
HEATER POWER DRIVER	: 6.3 A slow blow.
EVAPORATOR POWER DRIVER	: 6.3 A slow blow.
POWER SUPPLY BOARD	: 1.5 A for +5, +15, -15.

I.1 RS232 CONFIGURATION

The configuration procedure is invoked through the SPECIAL OPERATIONS menu (see Chapter E). Once invoked, it prompts the operator for a configuration code constructed as follows:

Code = 256*B + 16*W + 4*S + P , where

B is the baud rate code:
0=110, 1=150, 2=300, 3=600, 4=1200, 5=2400, 6=4800, 7=9600)
W is the word length code (1=7, 3=**8** bits; 0,2 are illegal)
Use 8 bits (code 3 only when parity is None (code 0) !
S is the stop bits code (0=illegal, 1=**1**, 2=1.5, 3=2 bits)
P is the parity code (0=**None**,1=Odd,2=illegal,3=Even)

The default code set-up after a Tabula Rasa is 1844, corresponding to:
9600 Baud, No parity, 8 data bits, 1 stop bit

I.2 USING THE RS232 INTERFACE

The serial interface can operate in two different modes:

The user-specific mode is used to emulate other VT controller communication protocols or to implement a user-defined protocol. Please, contact Stelar for further information on the availability of such modes.

The generic mode is always active, provided that the serial board is available. It simply associates certain input characters with the keyboard and ignores all others. When a character is received through the serial input, the system first tests whether it belongs to the "keyboard image" set. If so, it proceeds as though the corresponding key were pressed; otherwise, the character is ignored. The keyboard is also active on the first-come, first-served basis.

Two special input characters are reserved as serial output enable and disable commands. When the output is enabled, the controller echoes through the RS232 everything that appears on the display.
In this way, one can remotely control the unit and execute all the procedures described in this manual.

The generic mode "keyboard image" characters are:

VTC key	RS232 character	ASCII code
Digits	0-9 0-9	48-57
+/-	-	45
Frm/.	.	46
Cal/Prg	P	80
Enter/Print	;	59

Reset R 82
Adv A 65

Echo display ? 63

The pin-out of the RS232 connector at the rear panel of the VTC is listed in the following table.

Signal	VTC Cannon25 female	Cable male-female	PC Cannon 25 male	
GND	7		7	Gnd
RTS	4 high	--->	8	DCD
DTR	20 hndshk	--->	5	CTS and 6 DSR
Rx	3	<---	2	Tx
Tx	2	--->	3	Rx
DCD	8 rxenbl	<---	8	DCD
CTS	5 hndshk	<---	20	DTR

Note: On the VTC side, the DSR (data set ready input signal (pin 6) is NOT used.

The table also indicates an example of a VTC-PC connecting cable, based on the following assumptions:

* The presence of an active VTC and of the connecting cable is signalled to the HOST by asserting its DCD (Data Carrier Detect) line. The same signal returns to the VTC through the cable and enables its own DCD line.
* The VTC signals its readiness to receive (DTR output) by asserting the CTS (Clear to Send) and DSR (Data Set Ready) lines. The Host may test any of these lines before sending characters to the VTC.
* The VTC tests its own CTS (Clear to Sent) input before transmitting a character. The HOST controls that line through its DTR (Data Terminal Ready) output. If desired, the HOST may do the same through its RTS (Request to Send) output.

SAMPLE MONITOR PROGRAM FOR THE STELAR VTC

```
DEFINT I-N                                  'Use integers starting I-N
SCREEN 0: WIDTH 80                          '80 columns text screen
LOCATE 1,1,1                                'Display cursor at all times
CR$=CHR$(13)                                'Carriage-Return character
KEYS$="arpARP;.-0123456789?"                'Set of allowed characters
OPEN "COM1:9600,N,8,1" AS #1                'Open communication device
                                            'Parameters correspond to 'the VTC code
                                            1844
GETKEY:    C$=INPUT$(1)                     'Get a keyboard character
       I=INSTR(KEYS$,C$)                    'Is it one of the VTC set ?
       IF I=0 THEN GOTO GETKEY              'If not, sending it would be useless
       IF I<=3 THEN C$=MID$(KEYS$,I+3,1)    'Convert abc into ABC
       PRINT C$;                            'Display it
       PRINT #1,C$;                         'Send it to the VTC
       IF C$<>"?" THEN GOTO GETKEY          'Is an answer expected ?
       PRINT TAB(40);                       'Yes: tabulate to column 40
    RESPON0:T0=TIMER                        'Reset time-out count
    RESPON:    I=LOC(1)                     'Is there a received character ?
       IF I THEN                            'If yes:
```

```
I$=INPUT$(1,#1)                         ' Read it
PRINT I$;                               ' Display it
IF I$=CR$ THEN GOTO GETKEY          ' CR terminates the answer
GOTO RESPON0                        ' Not done: reset time-out, repeat
ELSE                                    'If not:
A=TIMER-T0                          ' Test time-out
IF A<3 THEN GOTO RESPON             ' If OK, wait !
GOTO GETKEY                             ' otherwise, return to txmit
END IF                              ' (transmit R to reset the VTC)
```

PARAMETERS TABLE # ___________ date __________________________

NOTE..

CP .... CI .... CD .... SF .... FP .... IB ....

IA .... MP .... MS .... NR .... NM .... LL ....

UL .... LS .... US .... EV .... FL .... SO ....

SS ....

===

PARAMETERS TABLE # ___________ date __________________________

NOTE..

CP .... CI .... CD .... SF .... FP .... IB ....

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